MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2018/2019

EEE2056 – PHYSICAL ELECTRONICS

(All sections/Groups)

2 MARCH 2019
2.30 p.m. - 4.30 p.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.
2. Attempt **All** questions. All questions carry equal marks and the distribution of the marks for each question is given.
3. Please write all your answers in the Answer Booklet provided.

Useful constants and coefficients:

Physical Constants

Boltzmann's constant (k)	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant (h)	6.626×10^{-34} Js
Thermal voltage@300K kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space (m_e)	9.10939×10^{-31} kg
Electron charge (e)	1.60218×10^{-19} C
Permeability of free space(μ_0)	$4\pi\times10^{-7}$ Hm^{-1}
Permittivity of free space of free space(ε_0)	8.85×10^{-12} Fm^{-1}
Avogadro's number(N_A)	6.022×10^{23} atoms/mol

Question 1

(a) (i) Briefly explain the principle of wave-particle duality using the de Broglie equation. [3 marks]

(ii) What is the de-Broglie wavelength of an electron at 1000 eV? [3 marks]

(iii) Use a diagram to explain the two properties of a wave packet to represent a particle. [4 marks]

(b) Use the wave-particle duality principle and the wave equation, derive the time-independent Schrödinger wave equation, $-\frac{\hbar^2}{2m}\frac{\partial^2\psi(x)}{\partial x^2}+V(x)\psi(x)=E\psi(x)$.

[7 marks]

(c) The energy of a free electron confined in a one-dimensional infinite potential well is quantized with $E=\frac{\hbar^2\pi^2n^2}{2mL^2}$, where n = 1, 2, 3, ….. and L is the width of the well. The normalized electron wave function is obtained from solving the Schrödinger wave equation is $\psi_n(x)=\sqrt{\frac{2}{L}}\sin\left(\frac{\pi x}{L}\right)$.

(i) Sketch the wave functions and probability distributions of electron in the first three allowed energy levels.

[6 marks]

(ii) Explain why the electron wave function is not zero at the boundary if the potential well is finite, where $V \neq \infty$ for $x < 0$ and $x > L$. [2 marks]

Continued….

Question 2

(a) Electrons in a metal is distributed according to the Fermi-Dirac probability function. State the Fermi-Dirac function and explain why this function approaches the Maxwell-Boltzmann distribution of neutral gas for electrons at high-energy states in a metal.

[5 marks]

(b) Consider a direct bandgap semiconductor with bandgap energy, $E_g = 1.35$ eV and its intrinsic carrier concentration, $n_i = 1.5\times10^{10}$ cm^{-3} at $T = 300$ K. This semiconductor is doped with impurity atoms so that the Fermi energy level, $E_F = 0.55$ eV above the center of bandgap.

(i) What type of impurity atoms is doped in the semiconductor, accepters or donors? Explain your answer. [3 marks]

(ii) Determine the majority and minority carrier concentrations in the semiconductor.

[5 marks]

(iii) The temperature dependence of carrier concentration in this semiconductor is shown in Figure Q2. What is the concentration of carrier N in the B region?

[2 marks]

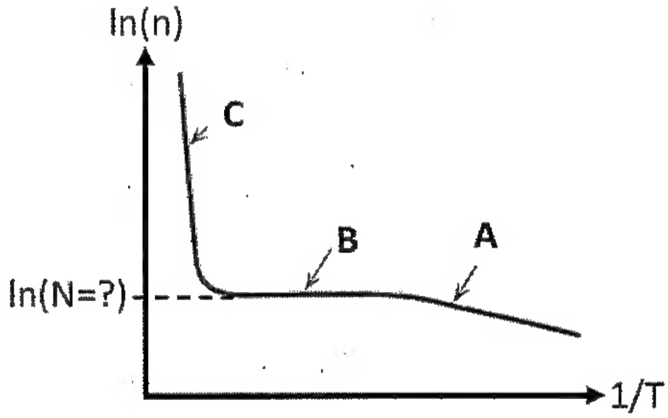

Figure Q2

(iv) Using simple diagrams to explain the mechanism that responsible for the characteristic of this semiconductor in region A, B, and C as a function of temperature.

[6 marks]

(v) What is the characteristic of this semiconductor if the doping density is increased so that the Fermi energy level E_F is 0.75 eV above the center of bandgap? Can you apply the mass action law for this semiconductor?

[4 marks]

Continued....

Question 3

(a) The interactions between the neighboring Silicon atoms are responsible for holding the Si crystal together. Use Figure Q3 to explain the formation of Silicon crystal and energy bands at lattice constant a_0 from N isolated Si atoms.

[6 marks]

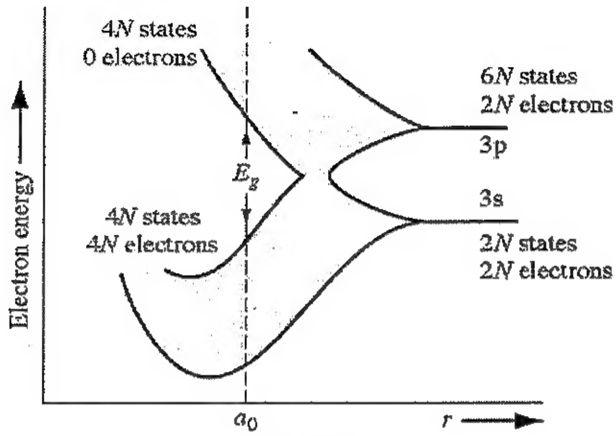

Figure Q3

(b) The electrons or holes transport in energy band of a semiconductor can be described in a quasi-classical manner in the sense of Newton's law of motion by the concept of effective mass.

(i) From the concept of a travelling wavepacket, show that this effective mass can be deduced from the energy-wavevector (E-k) diagram.

[7 marks]

(ii) Sketch the E-k diagram of a direct bandgap semiconductor where the electron effective mass in the conduction bandedge is much smaller than the hole effective mass in the valence band. Briefly explain your diagram.

[4 marks]

(c) Discuss the differences between electron-hole recombination in direct and indirect bandgap semiconductors with the aid of simple band diagrams.

[8 marks]

Continued....

Question 4

(a) Consider a Silicon abrupt PN junction without external bias at thermal equilibrium condition.

(i) Sketch the energy band diagram for this PN junction including the Fermi energy level across the junction. [4 marks]

(ii) Use your diagram to explain how the internal built-in potential voltage V_{bi} maintains its equilibrium condition at the junction. [5 marks]

(iii) Show that the built-in potential voltage V_{bi} can be expressed in terms of doping density (N_A and N_D), intrinsic carrier density (n_i) and temperature (T) in the PN junction as $V_{bi} = \frac{kT}{q}\ln\left[\frac{N_A N_D}{n_i^2}\right]$. [7 marks]

(b) An abrupt Silicon PN junction at zero bias in thermal equilibrium has impurity dopant concentrations of $N_A = 3\times10^{17}\,\text{cm}^{-3}$ and $N_D = 5\times10^{16}\,\text{cm}^{-3}$. Given that the intrinsic carrier concentration $n_i = 1.5\times10^{10}\,cm^{-3}$ at $T = 300\,K$.

(i) Calculate the Fermi level on each side of the junction with respect to the intrinsic Fermi level and determine the height of potential barrier at the junction. [6 marks]

(ii) Calculate built-in potential voltage V_{bi}. [3 marks]

End of the paper